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ORGANIC RESIDUES, DECOMPOSITION

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Introduction

Organic residues are carbon-containing compounds of biological origin. Decomposition is the breakdown of these complex organic materials into simpler components. Decomposition of organic residues in soil is an important ecological function whereby heterotrophic organisms consume various components, resulting in the physical and biochemical breakdown of organic materials and transformation and cycling of constituent elements. Biochemical composition, environmental factors, and diversity of organisms (*See* **Biodiversity**) play major roles in the dynamics and fate of organic residues in soil (*See* **Humification; Organic Matter:** Principles and Processes; Genesis and Formation). Decomposition is an important soil process that affects nutrient availability on a local scale (*See* **Nutrient Availability**) and environmental quality on a global scale by controlling carbon transformations (*See* **Carbon Cycle in Soils:** Dynamics and Management; **Carbon Emissions and Sequestration**), greenhouse gas emissions (*See* **Greenhouse Gas Emissions**), and nutrient fluxes (*See* **Nitrogen in Soils:** Cycle). The most common methods of determining decomposition are by mass loss of residues or by complete mineralization of organic constituents into end products of inorganic carbon (CO_2, CH_4), nitrogen (NH_4, NO_3), or phosphorus (PO_4).

Types of Organic Residues

Organic residues that enter the soil ecosystem are derived primarily from: (1) autotrophic organisms, including a wide diversity of plants, algae, and lichens; (2) animal tissue and manures; and (3) various organic additions from human activities, including pesticides, oil products, and synthetic compounds (*See* **Pollutants:** Biodegradation). The presence of heterotrophic organisms in soil, such as fauna and microorganisms, contributes directly to the type of organic residues through synthesis of unique compounds in their bodies, as well as indirectly through transformations of organic residues during decay and subsequent humus synthesis (*See* **Bacteria:** Soil; **Fauna; Fungi; Nematodes**).

Plant residues are, by far, the most dominant input of organic residues to the soil ecosystem. The quantity of residues produced varies with environmental conditions, but typically ranges from 200 to 2000 $g \cdot m^{-2}$ per year. The allocation of total plant biomass between roots and shoots depends upon a number of factors, including annual or perennial vegetation, soil fertility, climate, and various other soil physical and chemical characteristics. Generally, annual plants tend to have shoot to root ratios of more than 1, while perennial plants tend to have lower shoot to root ratios. Rooting depth of plants depends upon factors similar to those affecting shoot to root ratio. In general, about 50% of total root biomass is found in the surface 20 cm of soil. Accurate characterization of root inputs is difficult because of the intimate contact between roots and the soil-decomposer community, which acts quickly on substrates that are unprotected in the moist soil environment. The portion of root biomass that decomposes rapidly and does not persist in soil is often called 'rhizodeposition.' Rhizodeposits are typically composed of sloughed root cap cells, organic acids actively secreted by growing roots, lysates of root tissues, and high molecular weight root mucilage.

Plant residues are composed of: (1) highly labile intracellular compounds such as protein, starch, fructan, and chlorophyll and other pigments; (2) moderately resistant structural compounds such as cellulose and hemicellulose; and (3) resistant structural compounds such as lignin, polyphenols, lipids, and cutin. If isolated from the whole plant, individual components would decompose at different rates due to their susceptibility to microbial utilization (**Figure 1**). The rate of decomposition of whole-plant materials varies in response to the relative proportion of different intracellular and structural compounds, as outlined in the following.

For many field crop residues, C concentration is relatively constant at 41% of dry matter (**Figure 2a**). Protein concentration (estimated as 6.25 times the N concentration), however, varies greatly among residues by species, plant part, age, and management. The amount of C and N mineralized from crop residues varying in N concentration during incubation in soil is highly related to the C to N ratio of residues (**Figure 2b**).

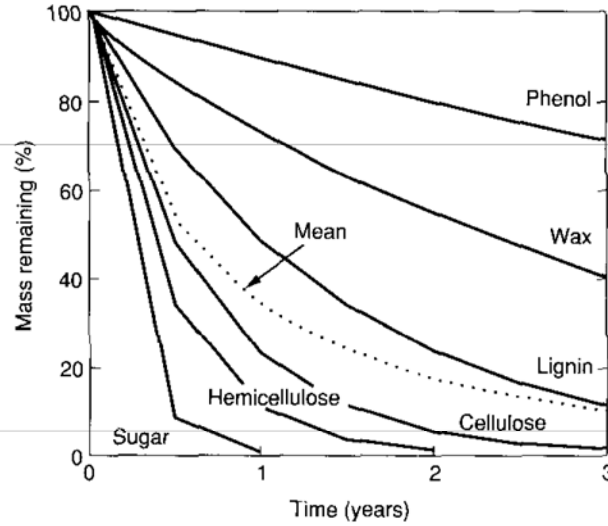

Figure 1 Theoretical decomposition of various components of plant cells, expressed as mass remaining during a 3-year period. Phenol, wax, and lignin groups decompose slower than the average rate of decomposition of plant material, and cellulose, hemicellulose, and sugar decompose faster. Mean proportion of the whole plant as phenol is 5%, as wax is 5%, as lignin is 40%, as cellulose is 20%, as hemicellulose is 15%, and as sugar is 15%. These proportions will vary depending upon plant species, age, fertility, and environmental conditions. Decomposition of organic residues typically follow first-order kinetics ($y_t = e^{k \cdot t}$, where y = mass remaining at time t and k is a nonlinear rate constant). (Source: Minderman G (1968) Addition, decomposition and accumulation of organic matter in forests. *Journal of Ecology* 56: 355–362.)

Leguminous herbaceous and woody plant species are often applied to soil as mulch or incorporated as green manure to improve soil fertility, especially in the humid tropics where decomposition conditions are ideal. Decomposition of these materials is dependent not only upon N concentration (positive), but also on the concentration of polyphenolics (negative), which are reactive compounds that can form stable polymers with various N compounds and slow decomposition (**Figure 3**).

The amount of lignin in plant tissue has a negative impact on the rate of decomposition, although some tissues may have a high protein concentration (**Figure 4**). Lignin is a high molecular weight polymer composed of phenyl propane units in cell walls, giving plants rigidity and resistance to microbial attack. Aside from polysaccharides, lignin is one of the most abundant biopolymers in nature. Lignin is relatively resistant to microbial decomposition, being limited primarily to a group of white-rot fungi that can completely decompose it (*See* **Fungi**). In addition, a diverse community of soil organisms is able to work in concert to decompose parts of the lignin structure slowly (*See* **Biodiversity**).

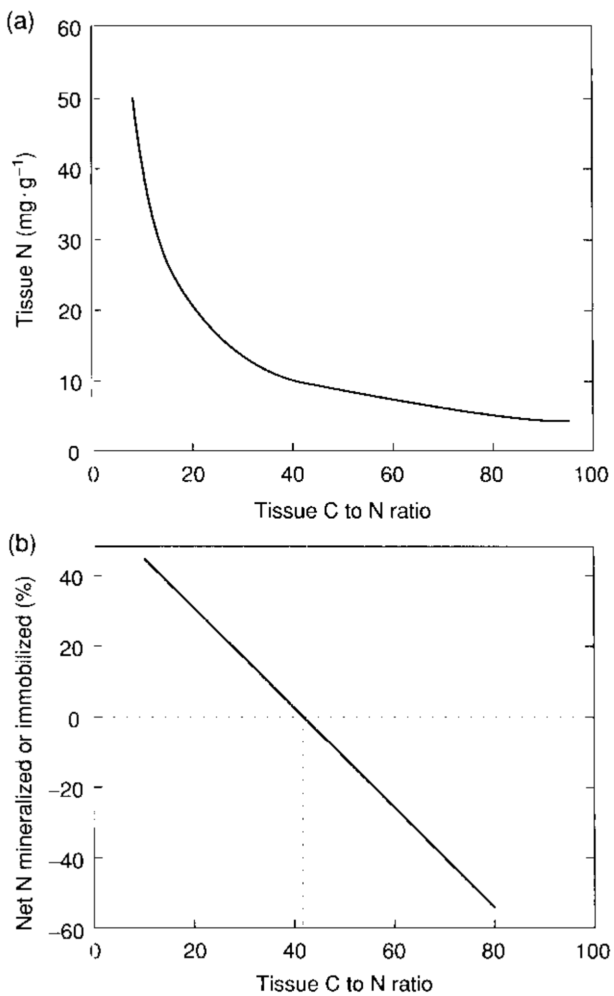

Figure 2 Relationship of C to N ratio of various crop residues with (a) N concentration and (b) net N mineralization during aerobic incubation. The close relationship between C to N ratio and N concentration (a) indicates uniform C concentration ($410\,mg\cdot g^{-1}$) and varying N concentration. Under defined incubation conditions (i.e., optimum temperature and moisture for 20 – 10 weeks), the percentage of N mineralized from plant tissues varying in C to N ratio (b) is positive when the C to N ratio is less than 42 (i.e., net mineralization of N) and is negative when the C to N ratio is more than 42 (i.e., net immobilization of N). (Source: Vigil MF and Kissel DE (1991) Equations for estimating the amount of nitrogen mineralized from crop residues. *Soil Science Society of America Journal* 55: 757–761.)

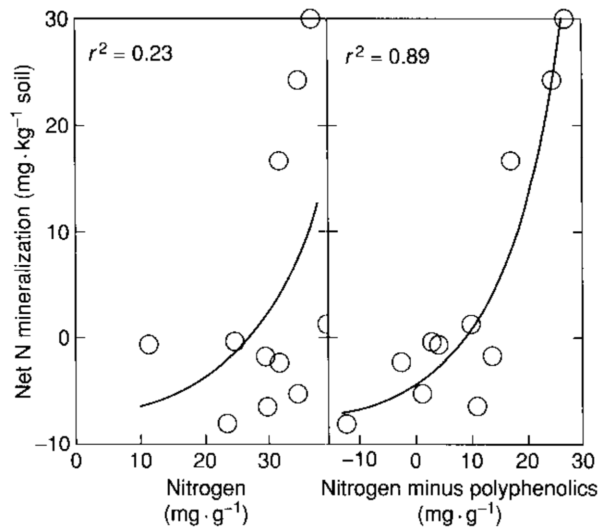

Figure 3 Relationship of N mineralization from different legume green manures (a) with N concentration and (b) with N concentration minus polyphenolic concentration. Although N concentration alone is typically a good predictor of potential N mineralization, condensation of N with polyphenolics can inhibit mineralization. Therefore, information on polyphenolic content of residues is needed to obtain a better prediction of N mineralization. (Source: Palm CA and Sanchez PA (1991) Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biology and Biochemistry* 23: 83–88.)

Environmental Factors

Water directly affects decomposition through its controls on activity and transport of soil microorganisms, solubilization of organic constituents, oxygen supply, and soil pH (*See* **Microbial Processes:** Environmental Factors). An optimum water content for decomposition is within a range that is not too high to limit oxygen availability and that is not too low to limit substrate availability and mobility of soil microorganisms. The ideal soil moisture condition for decomposition is between −10 and −50 kPa (or 30–60% water-filled pore space). Fluctuating moisture conditions in soil are common, but they do not necessarily have a negative impact on the ability of microorganisms to respond quickly to available substrates upon rewetting (**Figure 5**).

Temperature controls the biochemical activity of intra- and extracellular enzyme activities, as well as metabolic activity of most soil organisms responsible for the biodegradation of organic residues. For every 10°C rise in temperature, decomposition generally increases one- to two-fold.

Oxygen is a requirement for the dominant heterotrophic soil organisms responsible for decomposition. Oxygen serves as the most efficient electron acceptor during microbial respiration. When oxygen becomes limiting in soil, decomposition proceeds at a much slower rate. Alternative electron acceptors, including NO_3^-, Fe^{3+}, Mn^{4+}, SO_4^{2-}, and CO_2, can be utilized by anaerobic bacteria such as denitrifiers, sulfate reducers, and methanogens.

Soil pH affects decomposition of organic materials because of its direct effect on the activity of heterotrophic microorganisms. As soil pH decreases to less than 4, microbial activity is severely retarded and accumulation of organic matter can occur, as

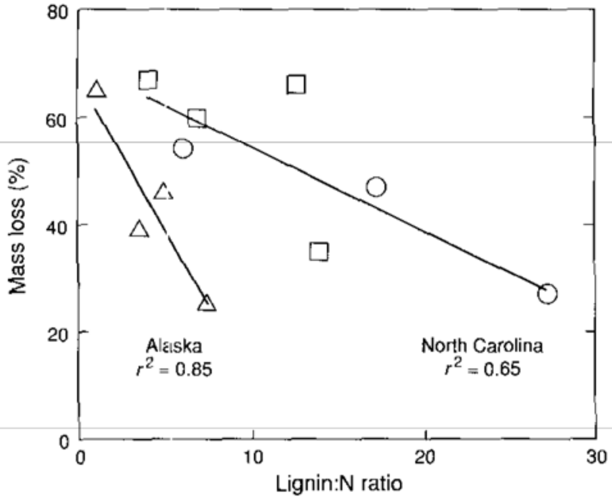

Figure 4 Decomposition of surface-placed residues as affected by their lignin-to-N ratio. Lignin is a polymer that is difficult for most soil microorganisms to decompose. Therefore, high lignin content reduces decomposition rate. At very low lignin content, decomposition of plant material would be similar whether the climate would be cold (Alaska) or warm (North Carolina). However, with increasing lignin content, decomposition is greatly reduced in a cold climate (Alaska) relative to a warm climate (North Carolina). Data from North Carolina are mass loss at the end of 1 year (circles: Blair JM (1988) Nitrogen, sulfur, and phosphorus dynamics in decomposing deciduous litter in the Southern Appalachians. *Soil Biology and Biochemistry* 20: 693–701.) and C loss at the end of 44 weeks (squares: Buchanan M and King LD (1993) Carbon and phosphorus losses from decomposing crop residues in no-till and conventional till agroecosystems. *Agronomy Journal* 85: 631–638.). Data from Alaska are mass loss at the end of 1 year. (Koenig RT and Cochran VL (1994) Decomposition and nitrogen mineralization from legume and non-legume crop residues in a subarctic agricultural soil. *Biology and Fertility of Soils* 17: 269–275.)

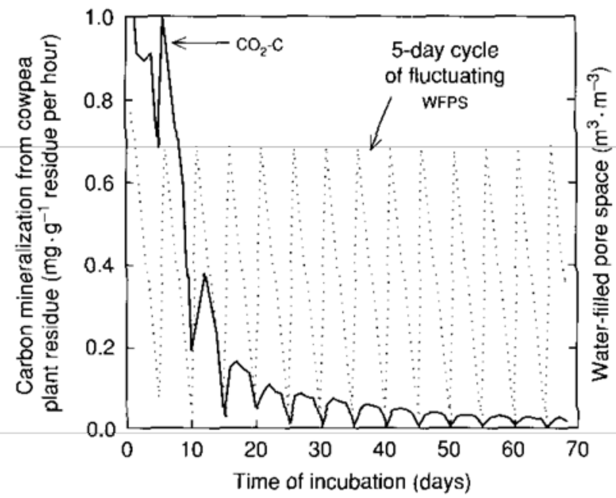

Figure 5 Carbon loss rate of decomposing leaf tissue during successive cycles of drying and wetting. Lowest points of each cycle have a water potential of −10 MPa. Extreme drying reduces decomposition, but decomposition resumes very rapidly upon rewetting. WFPS, water-filled pore space. (Source: Franzluebbers K, Weaver RW, Juo ASR, and Franzluebbers AJ (1994) Carbon and nitrogen mineralization from cowpea plants part decomposing in moist and in repeatedly dried and wetted soil. *Soil Biology and Biochemistry* 26: 1379–1387.)

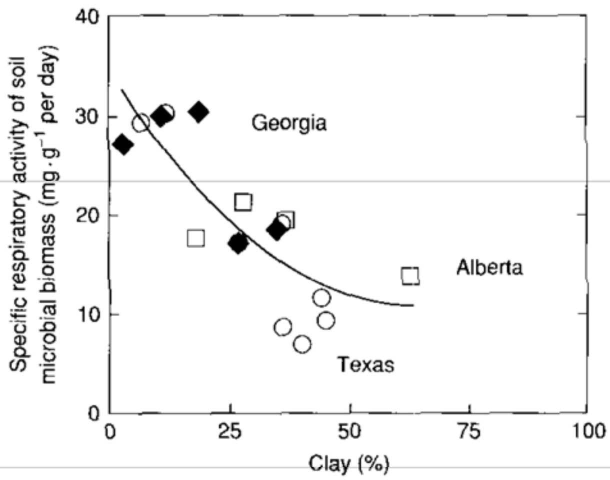

Figure 6 Relationship of microbial-specific mineralization with soil clay content (AJ Franzluebbers, unpublished data). Soils with fine texture have higher clay content and typically more aggregated soil that can protect a portion of the soil organic matter within aggregates. The higher specific respiratory activity of microbial biomass in coarse-textured soil than in fine-textured soil suggests a lower level of protection of the microbial community against predation by other microorganisms and by soil fauna.

especially evidenced by the thick litter layer that often develops under forests on acidic soils (e.g., mor).

Organic materials can become isolated, and even protected from decomposition to some degree, once they become incorporated into water-stable soil aggregates (*See* **Aggregation:** Microbial Aspects). Protection within these aggregates may be due to the physical barrier that limits soil faunal activity and, at times, due to low oxygen concentration that limits soil microbial activity (*See* **Structure**). Soil texture (*See* **Texture**) offers a similar physical limitation on organic matter decomposition, where the pores in coarse-textured soils are freely accessed by a wide variety of micro-, meso-, and macrofauna. Pores in fine-textured soils are often more diverse, with micropores that limit faunal activity and protect organic matter from decomposition typically not present in coarse-textured soil (**Figure 6**).

Soil management can have large impacts on residue decomposition by altering the physical environment and controlling the supply of substrates. Whether organic residues are left on the soil surface or incorporated into soil (*See* **Cultivation and Tillage; Conservation Tillage**) affects the moisture and temperature regimes they occupy. Generally, incorporated residues decompose faster owing to more consistent moisture and temperature conditions in the soil than on the soil. The type of cropping can alter the timing, quantity, and quality of residues added to soil (*See* **Crop Rotations**). Residues that become available to soil organisms for decomposition during dry or cold periods will decompose at a different rate and possibly undergo different transformations because of different participating organisms than residues that become available during hot or wet periods of the year. Whether crops are perennial or annual can influence: (1) the level of soil disturbance, (2) the type, timing, and quantity of substrates supplied to the soil, and (3) the placement of residues.

Organism Interactions

Various types of organisms feed upon specific components of organic materials in soil. This complexity of interactions among organisms can be illustrated as a food web (**Figure 7**), where bacteria and fungi are principal decomposers at many points within the web and progressively larger organisms tend to feed on more specific components of organic material within the food web (*See* **Food–Web Interactions**). The soil microbial biomass plays a pivotal role in the decomposition of organic inputs from plant and animal residues and the breakdown and transformation of organic matter to and from slow and passive pools (**Figure 8**).

The presence of soil fauna (*See* **Fauna**) often facilitates decomposition by: (1) comminuting plant residues, which exposes a greater surface area to attack by soil microorganisms; (2) transporting organic residues to new locations in the soil, which facilitates decomposition, interaction with soil nutrients, and isolation from certain environmental conditions; (3) inoculating partially digested organic residues with specific bacteria and enzymes (*See* **Enzymes in Soils**); and (4) altering physical characteristics of soil by creating burrows, fecal pellets, and distribution of soil particles, which influence water (*See* **Water, Properties**), air (*See* **Aeration**), nutrient (*See* **Nutrient Availability**), and energy (*See* **Energy Balance**) retention and transport in the soil.

Nutrient Cycling

Nitrogen is a key element that is held within organic residues primarily as proteins and amino acids and released to the soil environment as NH_4^+ through the process of mineralization (*See* **Nitrogen in Soils: Cycle**). Decomposition of organic residues is

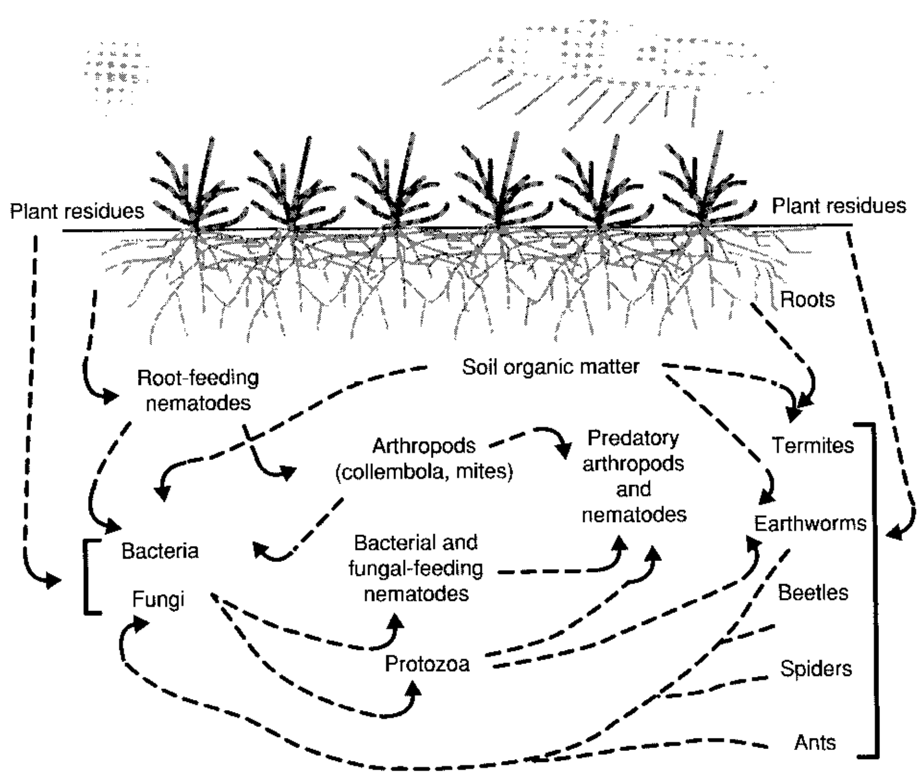

Figure 7 A soil food web. Plant residues are fed upon by various organisms residing in soil. In turn, the growth and remains of these organisms are fed upon by other heterotrophic organisms in soil until nearly all energy embedded within the organic molecules has been exhausted.

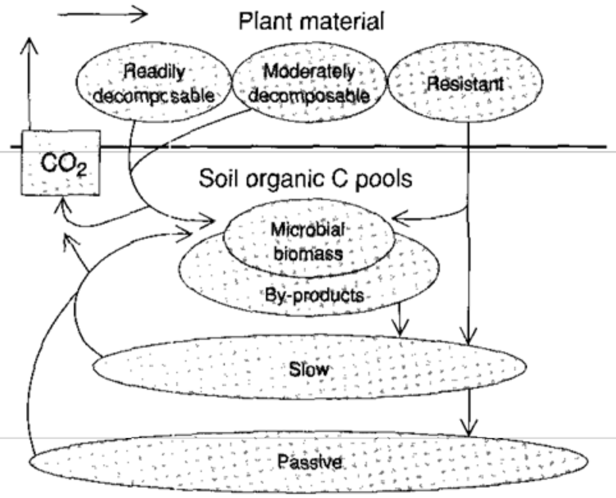

Figure 8 Pools of carbon in soil and the central role of microbial biomass in transforming organic residues into soil organic matter and releasing carbon dioxide into the atmosphere.

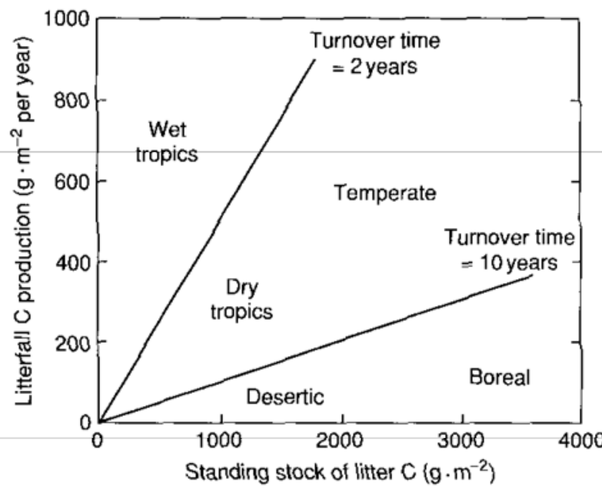

Figure 9 Decomposition estimates based on annual litterfall and standing stock of litter at the forest floor under different environmental conditions in the world. (Source: Olson JS (1963) Energy storage and the balance of producers and decomposers in ecological systems. *Ecology* 44: 322–331.) With high stock of litter at the forest floor and low litterfall production, slow decomposition occurs due to limited moisture or cold temperature. With low stock of litter and high litterfall production, rapid decomposition occurs due to plentiful moisture and warm temperature.

necessary to release organically bound N into inorganic N, which can then be taken up by plants.

Phosphorus is bound organically in plants primarily as deoxyribonucleic acid (DNA) and the energy-transfer molecules adenosine diphosphate (ADP) and adenosine triphosphate (ATP). Mineralization of P from organic residues can supply not only a portion of plant requirements, but also the rapidly growing microbial population that has a high demand for P to meet its ATP production requirements (*See* **Phosphorus in Soils:** Overview).

Carbon is the primary element in organic materials, representing 35–45% of the dry weight of most plant materials, 40–50% of the dry weight of animal manures, and 45–55% of the dry weight of soil humus. In general, C undergoes complete cycling from atmosphere to plants to soil organic matter to atmosphere (*See* **Carbon Cycle in Soils:** Dynamics and Management; **Greenhouse Gas Emissions**). The residence time of C in the terrestrial sphere can be relatively short in warm–moist environments and longer in cold–dry environments (**Figure 9**), but globally the quantity of C fixed within plant biomass each year is believed to be balanced by the quantity of C released to the atmosphere through decomposition.

Decomposition is an important process that returns organically bound nutrients back to nature for utilization and cycling. On a global scale, this vital ecosystem function balances the autotrophic production of organic matter through photosynthesis. An imbalance in these opposing processes would lead to either: (a) accumulation of organic residues, with a consequent reduction in plant-available nutrients, which could ultimately reduce net primary productivity without external nutrient inputs; or (b) depletion of soil organic matter reserves, which could facilitate greenhouse gas emissions and global warming, thereby depleting inherent soil fertility and reducing net primary productivity. Decomposition is a vital ecosystem function that sustains life on Earth.

Future Advances

Decomposition of organic residues has been historically and extensively studied, and yet much remains to be learned about the decomposition mechanisms and fate of residues in different environments. Of particular deficiency in our current knowledge are the dynamics and interactions with soil of plant root production and decomposition. More detailed chemical composition and fate of different organic residues are needed. Analytical techniques have relied in the past upon acid digestion procedures that are not particularly well suited for analyzing specific molecular classes of compounds. Future analytical techniques will probably rely more on a combination of spectroscopic, chemolytic, and thermolytic analyses to describe both initial chemical properties and the temporal changes in properties during decomposition.

List of Technical Nomenclature

%	Percent
ADP	Adenosine diphosphate

ATP	Adenosine triphosphate
C	Carbon
C	Celsius
d	Day
DNA	Deoxyribonucleic acid
g	Gram
kg	Kilogram
kPa	Kilopascal
m	Meter
mg	Milligram
Mpa	Megapascal
N	Nitrogen
P	Phosphorus
yr	Year

See also: **Aeration**; **Aggregation:** Microbial Aspects; **Bacteria:** Soil; **Biodiversity**; **Carbon Cycle in Soils:** Dynamics and Management; **Carbon Emissions and Sequestration**; **Conservation Tillage**; **Crop Rotations**; **Cultivation and Tillage**; **Energy Balance**; **Enzymes in Soils**; **Fauna**; **Food–Web Interactions**; **Fungi**; **Greenhouse Gas Emissions**; **Humification**; **Microbial Processes:** Environmental Factors; **Nematodes**; **Nitrogen in Soils:** Cycle; **Nutrient Availability**; **Organic Matter:** Principles and Processes; Genesis and Formation; **Phosphorus in Soils:** Overview; **Pollutants:** Biodegradation; **Structure**; **Texture**; **Water, Properties**

Further Reading

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